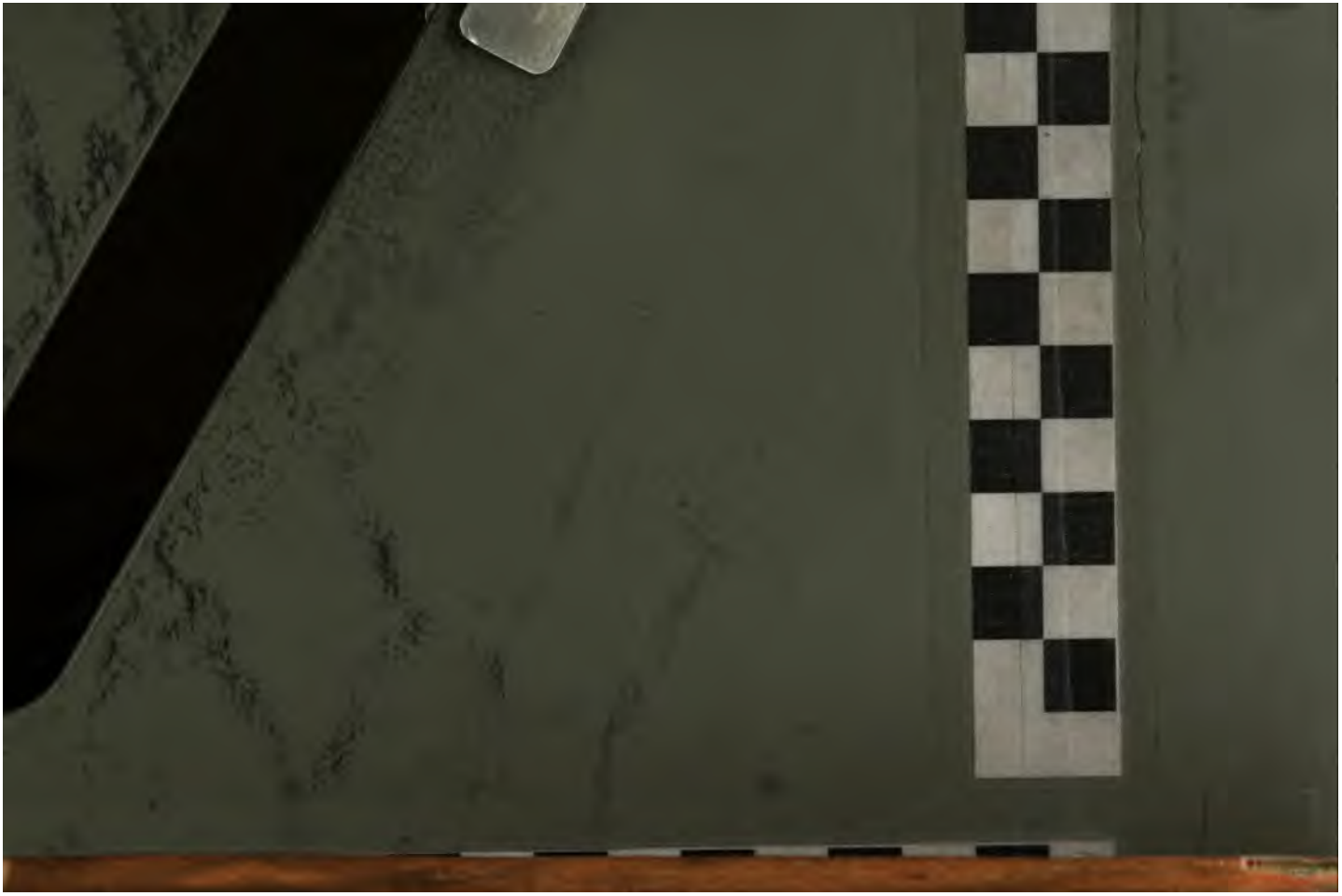

THE CAUSES

WHICH PRODUCE THE

GREAT PREVAILING WINDS

AND

OCEAN CURRENTS,

AND THEIR

EFFECTS ON CLIMATE.

BY

C. A. M. TABER.

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PREFACE.

THE explanations contained in this pamphlet proceed from many years' experience on the several oceans of the globe. Still, however large such unnoted experience may have been, I am well aware of the presumptuous position assumed while drawing from such a source to advance new explanations of natural causes which have been long studied and repeatedly expounded by learned writers. But it is well to consider that such writers have never yet been able to explain satisfactorily the causes which produce the great prevailing movements of the atmosphere and ocean. And for this reason dissatisfaction is frequently expressed at our imperfect insight into phenomena so varying and contradictory to the explanations they have given. Therefore after a long familiarity with the working of the great prevailing winds and ocean currents, I am led to draw different conclusions in regard to their tendency, and the manner in which they are produced, than has yet been published. It is now generally known that the great prevailing winds and ocean currents do greatly influence the climate of the high latitudes, consequently their operations are shaping the future climatic condition of a large portion of the civilized world. Hence, I am led to point out what I conceive to be the tendency of such operations, and wherein they differ from current theories which leave

out of consideration the gradual change of climate which is now progressing in the high northern latitudes. In fact, so comparatively rapid is this climatic change in many northern countries we even find it verified in modern history.

It will be seen that a portion of the facts brought forward to maintain my assertions are taken from well known authors. But this summary is necessarily far too limited to admit full explanations, or even to note many important facts which would greatly strengthen the conclusions I have drawn.

C. A. M. TABER,
Wakefield, Mass., U. S. A.

THE CAUSES WHICH PRODUCE THE GREAT PREVAILING WINDS.

For many years extensive observations have been made to obtain information respecting the changes which are taking place in the atmosphere on different parts of the globe, and through this means much knowledge has been gained regarding the true extent, direction, and velocity of the great prevailing winds.

But with increased knowledge confidence is not proportionally strengthened as it should be in the theories hitherto advanced for explaining their cause.

The theory now taught in our schools is founded on Halley's explanations given nearly two centuries ago; which was long before the general direction of the great aërial currents was known. Yet because of its seeming plausibility for explaining the cause of such prevailing winds as had then been reported by navigators it was generally accepted, and has ever since served to mislead persons striving for information in that direction. Such inquirers supposing the generally accepted theory to be true, have usually been disposed to disregard or undervalue the constantly increasing observations which are in direct conflict with its teachings. The author of this paper commenced with the supposition that Halley's theory explained the true causes which produced the great prevailing winds; but was induced, after many years experience with the winds of the several oceans of the world, to abandon it, even while the barrenness and inadequacy of other theories afforded still less reasonable explications. Yet wishing to find a consistent explanation for the great aërial circulation of the globe, the natural ef-

fects that should be produced through the diurnal heat of the sun were brought under consideration, and found to harmonize with the great prevailing movements of the air; besides being adequate to perform the world-wide work which is so constantly carried on in the atmosphere.

The object of this paper is to show in a summary manner how the author conceives such work is accomplished, and to point out some of the principal defects of Halley's theory.

This widely accepted theory as now explained is declared to consist in "a great system of surface-currents continually streaming out of bands of high atmospherie pressure, towards a belt of low-pressure around the equator on one side, and towards the poles on the other, and of upper air-currents continually flowing away from the low-pressure areas,—a system set in motion by the greater warming of the equatorial regions by the sun and consequent low-pressure of the atmosphere there than in the regions on either side. It might be that those assumed currents with an uninterrupted circulation should have a direct north and south course; but owing to the diurnal rotation of the earth an object at the equator is carried along with far higher speed than an object nearer the pole. Hence when a current of air travels away from the equator northward or southward it moves in a region of less velocity, yet at the same time carries with it part of its equatorial rapidity of rotation. Now as the earth rotates from west to east, a current of air flowing from the tropics, north or south across the high latitudes, would be forced towards the east, thus causing a south-westerly wind in north latitude, and a north-westerly wind in south latitude. On the other hand, the air which travels from the higher latitudes towards the equator is always getting into regions where the speed of rotation increases; therefore it lags behind, causing a north-east trade-wind north of the equator, and on the south side a south-east trade-wind, the two winds meeting at the equator, where their vapors are collected, thus producing a calm belt of rain clouds encircling the earth."

However correct this theory may appear on certain portions of the globe, it fails to coincide with observations made

on extensive parts of tropical oceans far removed from land, the very places where they should be proved. Such off-shore waters, according to the experience of persons cruising over them, have no regular north-east and south-east trade-winds separated by a calm-belt, but rather, a prevailing easterly wind veering a few degrees north and south of east. Such is the direction of the prevailing winds of the tropical Pacific Ocean where removed from the influence of the American continent. The fact is the equator or latitudes near it do not possess a decided space of rarefied air sufficient to attract the atmosphere of other portions of the torrid zone lying parallel with such latitudes, except in the vicinity of heated lands. The ocean currents from the north and south meeting near the equator prevents a continuous band of heat from being maintained throughout the central portion of the torrid zone. Therefore the north-east and south-east trade-winds prevail only on parts of the ocean lying to the west of continents where the air-currents which move toward the equator are mainly governed by the attraction of heated tropical lands. And when we look for winds streaming out of bands of high atmospheric pressure towards the equator, they are only to be found on parts of the ocean corresponding to the calm rainy regions in the vicinity of continents.

On sailing over the North Atlantic in latitudes bordering the tropic from the longitude of 35° west to the American shores, air-currents are not found to be flowing towards the equator; their general movement ranging from the eastward, and more frequently from the equatorial regions than toward them. And this is the prevalent course of winds on the borders of the torrid zone on the central and western portions of all oceans. Judging from these facts there is lack of proof to show that the easterly winds of the tropics are caused by the air being left behind while on its way from the high latitudes to the equator, through the rotation of the earth, as described in Halley's theory.

The principal differences in atmospheric pressure being caused by temperature, the daily passage of solar heat over wide lands and seas, appears sufficient to give a prevailing

westerly motion to the surface winds of the tropical latitudes. For when we consider the daily passage of the heat of the mid-day sun over the earth's surface it appears that the air on the places passed over must be constantly cooling until the next rising of the sun; while the quicker heating of the air is performed in front of the sun, from sun-rise until the most heated part of the day. This diurnal heating and cooling of the lower atmosphere of the tropical zone causes an uneven atmospheric pressure towards the east and west. For it has been found from numerous observations made within the tropics, that the lowest barometric pressure is during the hour of greatest heat. So the heaviest atmosphere is found in the morning after the nocturnal absence of the sun. But between these extremes of atmospheric pressure barometric oscillations take place; which are supposed to be caused by watery vapor. Yet they are not sufficient to change the general effect produced by the greater extremes of atmospheric pressure caused by temperature. Therefore, the rarefied atmosphere caused by a vertical sun is the attractive point for the cooler air of the east and west. Thus it may seem that the attraction in front of the sun is equal to the attraction in its rear. But we should consider that the attraction following the sun has double the time to act than the opposing force in front of the tropical noon; therefore the last-named force moves the air back a less distance than it is carried forward by the longer attraction, because the more hurried air meets with greater resistance from friction while passing over the earth's surface, besides the greater lessening of pressure in its rear to be overcome with an increased rate of speed.

There is not a more important truth in physics than this: for the difference in favor of the most enduring air-current constantly creates powerful agents to increase its strength; for the prevailing wind not only carries the vapors along with it to be condensed on the western shores of tropical oceans, thus constantly setting free vast stores of heat and thereby greatly adding to its power; also, during such operations, the surface waters of the sea gain a higher tempera-

ture on the leeward sides of oceans through long exposure to the warm winds which sweep them westward.* And furthermore, the heated lands lying west of tropical seas add still further attraction to strengthen the great primary air-current on its western course. Consequently, the counter attraction in front of the sun being a retreating force, finds an opposing wind already in possession of places it passes over, which it must overcome before it can create a counter-wind; which work it generally fails to accomplish, having little power to create auxiliary forces. Yet evidently it is able to weaken the prevailing wind. For it is a fact well known to navigators that the trade-winds generally lose strength as the heat of the day increases, their weakest point corresponding to the highest temperature. And it is through this counter-attraction in combination with heated lands, that sufficient strength is obtained on some parts of the tropical zone to overpower the easterly winds, thereby creating calms, counter-winds, and monsoons. But the attraction following the sun maintains the greatest influence out on the sea, therefore the greater portion of tropical winds generally move on a western course.†

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* After an experience on lofty islands on widely separated portions of the torrid zone, it appears to us that the diurnal changes of temperature in the tropical wind-belt are more uniform and contrasted in that portion of the trade-winds which move above the trade-clouds, than on ships where observations are generally made, and where watery vapors largely abound. This may happen because the layer of trade-clouds and the abundant vapors below them prevent a rapid radiation of heat from the ocean's surface. Professor Tyndall has declared this fact in his admirable lectures on radiation. This learned writer also says that the chilling of the atmosphere is much greater at night on elevated regions than on low places. Therefore in the upper portions of the trade-winds above the trade-clouds, the daily received heat of the sun and the gradual cooling through the night should be more regular and contrasted than at the surface of the sea. Hence the attraction which follows the sun would maintain a more overpowering influence in the elevated region of the trade-wind than near the ocean's surface. And this fact explains why the upper portion of the trade-winds moves with greater speed than the winds nearer the ocean's surface. Still this difference in velocity is caused in part through the friction of the lower wind against the sea.

† Professor Wells, in his text-book entitled "Familiar Science," illustrates in the chapter on winds, how the air-currents should follow the heat of a vertical sun around the earth, because of the cooling of the

In this explanation of the easterly winds of the tropics, it will be seen that the attraction which causes them is originally a weak force; yet sufficient to create powerful agents which combine to make it a prevailing power over the greater portion of the torrid zone. This original weakness explains why it does not usually extend far outside of the tropics. The high latitudes being less exposed to solar heat, the diurnal atmospheric variations have less power to act. In fact they were first discovered by Humboldt in the tropical latitudes and have less perceptible regularity outside of them.

Thus it appears that the attraction following the sun from east to west in the tropical latitudes, causes an easterly wind to sweep around the earth, except in regions where the attraction of heated lands combines with the opposing attraction in front of the sun, and thereby gains sufficient strength to overpower it: thus causing counter winds, and calms. But when we keep in mind the natural effect of this great easterly wind sweeping around the earth, except where turned from its course by obstructing lands, we find that the counter westerly winds which prevail in the high latitudes are in the position of eddy-winds, being largely caused by the great tropical air-current which follows the heat of the sun over wide oceans. This statement appears evident when we realize that a light fluid while moving through an inert mass of like composition, must, when confined within proper limits, create an eddy-current outside of the original stream. Even so heavy a fluid as water shows this tendency in a high degree, while the air having much greater fluidity is far more subject to this efficient property. Hence the great primary winds of the tropical zone following the heat of the sun from east to west, over wide seas, must necessarily disturb the atmosphere remote from the sun's influence, lying

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atmosphere in its rear; but ignores the constant opposing attraction in front of the mid-day heat except when approaching high mountains: consequently he neglects to state the manner in which it is overcome by the attraction following the sun; and in the following section of the chapter abandons his first explanation and teaches Halley's theory.

north and south of its track; and this disturbance must naturally create a counter-motion. We see this performance on the North Atlantic Ocean, where the prevailing winds, like its great aquatic currents, move around the mid-ocean waters of the Sargasso Sea. The trade-winds, through the intervention of the eastern continent, in the vicinity of the Madeira Islands, are found blowing from the north of east; and while a portion of them move down the African coast to the calm regions south of the Cape Verde Islands, we also find that a still larger portion of the air-currents gradually turn out in mid-ocean, south of the Sargasso Sea, towards the west, being attracted by the daily passage of the sun and the higher temperature of the waters of the western Atlantic. But, on or before reaching the Gulf of Mexico, we find a considerable portion of the winds frequently moving towards the north-west; being gradually turned from their natural mid-ocean course by mountain ranges, and attracted by the heated plains of North America; thus causing their vapors to furnish rain for the United States, and likewise to supply air, displaced by the winds which generally move eastward from the Rocky Mountains to the Atlantic, and so again to traverse the ocean toward the eastern continent, until a portion of them are turned southward, along the Atlantic coast of Southern Europe; being deflected by mountain ranges and attracted by the heated lands of tropical Africa; thus uniting again with the great easterly wind-belt of the tropics.

Under such conditions, there can be no other prevailing movement to the surface winds of the high latitudes of the North Atlantic, because the air drawn southward, from the eastern North Atlantic towards the rarefied atmosphere of tropical Africa, and the displacement of air caused by the trade-winds, must be replaced by such surrounding atmosphere as can be the most easily attracted to fill the vacancy. The atmosphere of Europe not being available, because of it also being an attractive region, therefore the atmosphere over the North Atlantic, lying west of Europe, is drawn eastward to supply the vacancy caused by the tropical winds. And

while a large portion of the air thus moving eastward turns southward to supply the tropical winds, a still larger portion moves onward to the heated plains and valleys of Europe and Asia. Yet while on its way over the land, it frequently turns southward through the valleys of southern Europe, towards the heated plains of Sahara, so that the prevailing winds of the Mediterranean Sea are from the northward.

In this way we account for the great prevailing winds of the North Atlantic Ocean, which gyrate with more or less regularity around its vast central waters. Still in addition to the forces we have pointed out for creating the westerly winds of the high latitudes, it is probable that they are assisted by the attraction in front of the sun, it having a more concentrated power than the attraction following the sun. Therefore it should act outside of the tropics, especially with the general tendency of the atmosphere in its favor; while the more diffused attraction following the sun would lose its commanding power on being weakened, and consequently easily overcome, especially with the conflicting influences it must encounter in the high latitudes. That the attraction in front of the sun does assist the westerly winds appears evident on account of their frequent raising with the sun, and gradually losing strength on the approach of evening.

Moreover, this attraction in front of the sun from west to east, appears to be one of the greatest disturbers of the atmosphere of North America. The strong westerly gales which sweep over its central and eastern portions, and continue on at times over the Atlantic, are first set in motion over the great plains which spread east from the Rocky Mountains. The frequent rush of wind over this region is mainly caused through the great inequality of temperature in front of the noon-day sun, extending from the eastern portion of the plains to the mountains. The eastern lands being less elevated, and the earliest exposed to the rays of the advancing sun, the heated atmosphere over them has strong attraction for the cooler air of the western highlands. The opposing attraction following the sun serves only to quiet, through the night, the air currents thus set in motion in the morn-

ing.* But should a low barometric pressure be brought about in the atmosphere which rests on the Atlantic, in the westerly wind-belt, because of such atmosphere having been drawn upon to supply the trade-winds or to replace the rarefied air over the heated lands of the eastern continent, in the manner we have explained, the strong westerly winds rushing from the Rocky Mountains are enabled to entirely overcome the attraction following the sun, and so continue on their eastern course over the ocean as far as the low atmospheric pressure maintains its attraction, which at times extends east over Europe. Yet while these gales are sweeping over the Atlantic, along the westerly wind-belt, the atmosphere over the waters lying between these winds and the easterly tropical winds are comparatively undisturbed, like the waters of the Sargasso Sea, over which they rest, because the surrounding atmospheric disturbances are generally acting in opposition.

The stormy westerly wind-belt of the North Atlantic being mostly destitute of islands, the atmospheric disturbances over its larger portion cannot be recorded in time to be of much benefit to navigators. Still a knowledge of the atmospheric disturbances moving over the islands along its borders, may predict with considerable certainty great disturbances over other parts of these waters.

The great rainy region to the southward of the Cape Verde Islands is caused by the heated lands of Africa which warm and rarefy the atmosphere lying over them, thus attracting the cooler air of the adjacent seas; this attraction, combined with that in front of the sun, is sufficient to over-

* The eastern lands of North America being heated by the rising sun earlier than its more western regions, thus causes the air to be attracted in an easterly direction from the Rocky Mountains, over the eastern lowlands, towards the Atlantic Ocean. The air thus drawn from west to east, is probably one cause of the air currents frequently moving from the Gulf of Mexico, up the Mississippi Valley, in order to take the place of air attracted east by the heat of the morning sun. In the winter season, the cold air of the arctic regions is frequently attracted to these great plains through the same cause, and this cold air is probably hurried eastward through the high temperature of the Gulf Stream waters, and also because of the air being drawn from the eastern side of the ocean, in the manner we have shown.

come the attraction which follows the heat of the sun, and thereby causes a light westerly wind to blow on the Atlantic, near the equator. This wind meeting the easterly air currents which blow over the continent, causes a calm centre of highly rarefied air. Hence, this calm centre is able to attract the vaporous winds from the South Atlantic, as well as such of the North Atlantic winds as blow down the Sahara coast past the Canary and Cape Verde Islands. The air of these winds which waft heat and vapor from many directions, being rarefied, is in a fit condition on meeting to ascend into the upper atmosphere; during which process the collected vapors are condensed, causing heavy rain. But these immense volumes of ascending air on reaching great heights, in order to gain an equilibrium, necessarily cause a lateral pressure on the surrounding atmosphere, while the air thus forced away and grown heavy through cooling naturally sinks over the region from which it was at first attracted. Consequently such places of descending air probably show a high atmospheric pressure, especially on the ocean, from which air-currents are generally flowing towards regions of low atmospheric pressure. Yet these places of heavy atmosphere are not bands reaching around the earth or even across oceans; being usually located near the torrid zone, and on the eastern portion of the mid ocean waters; and it is probable that they correspond to the calm rainy regions towards which their currents flow.*

Similar aërial operations are repeated in the circulation of the atmosphere of the Pacific Ocean. But the places of high barometric pressure, and the corresponding places of low pressure in the equatorial calm regions, are never extended bands reaching across the seas; for they do not exist on the western portion of the wide ocean.

Therefore, such places entirely fail to represent bands encircling the earth as explained in our text-books.

* Mahry, writing on this subject, says that the upper air-currents should move exactly parallel to the surface winds; because the surface winds drawn toward heated calm regions in the torrid zone would naturally attract the upper air back to the places from which it was at first drawn.

Although the attraction following the sun is a weak force, still it is generally able to move the air of the tropics from east to west over the greater portion of the torrid zone—its work being mostly confined to the tropical latitudes in moving surface winds parallel with the equator; hence, such winds move for long distances under a torrid sun, and consequently do not so rapidly exhaust the diurnal heat from which they derive their motion, as would be necessary if they were moved by equatorial heat, as explained by Halley. Therefore, it is because of the attraction which follows the sun that the present temperature of the earth is preserved, for through it the tropical winds are crossing wide oceans, and constantly gaining strength by carrying heat in vapor to be condensed on leeward shores; and also to gain yet further power on their passage over the sea by increasing the temperature of the water as they move westward, thus causing them to be great conservers of heat.

But when we accept equatorial heat as the prime mover of the atmosphere, as described by Halley, we certainly give it an unreasonable task to perform, because of the rapid consumption of heat which would take place through such a process. For we should consider that one third of the weight of the atmosphere of the torrid zone is moved as a surface wind; and should it blow towards the equator all around the earth with a velocity common to tropical air-currents, the time required for solar heat to rarefy and raise into the upper atmosphere such immense masses of air appears too limited. And when we realize the great quantity of heat which would rapidly find its way into space should all tropical winds meet near the equator around the earth, it appears that the sun does not furnish sufficient warmth to maintain such a heat-consuming aërial circulation. Therefore, instead of a calm-belt reaching around the earth, we find only limited calm places caused by hot tropical lands, and maintained mostly against the western shores of continents. Such regions receive heat in the form of vapor from many directions over the ocean, besides being places of attraction for the hot winds of torrid deserts and other heated tropical lands.

And it is only only amid such great accumulations of heat that the rarefaction of air is sufficient to carry out the aërial workings of a great rainy calm centre.*

The average heat received by the sun on a portion of the earth equal to a degree of longitude reaching from the poles to the equator, could not perform such work as is accomplished over a degree of longitude in any of the rainy calm centres. For the latitudes outside of the torrid zone do not furnish heat for such work; but, on the contrary, they are great consumers of equatorial heat. The great aquatic currents on the western sides of oceans are continually transporting heat away from the equator into the high latitudes; and by such means the equatorial regions are parting with much more heat than they receive from regions outside of the tropics; at the same time the cold return currents of the ocean constantly meeting at the equator and cooling the waters, prevents a central band of equatorial heat from forming over the greater portion of the torrid zone.

Thus when we estimate how much concentrated heat is required to create equatorial calm centres such as exist against the western shores of continents, it will be seen how few of them can be maintained on the earth. Consequently the air on the greater portion of the torrid zone cannot be attracted towards the equator to be left behind, because of the rotation of the earth, but obtains its westerly motion through the attraction caused by the heat of the sun which daily moves across oceans from east to west, in the manner we have shown.

Yet the easterly winds of the tropics on approaching the land are always turned towards such regions as lie more

* Even in the calm regions the rain is not continuous, especially on the sea, for the nights are frequently clear and fine. The reason of this is, the air being heated by the vertical rays of the sun, ascends, carrying with it the vapors which have been collected by the centering winds during other portions of the day. The ascending air which carries these masses of vapor being rarefied and chilled in consequence of expansion, and also losing much of the heat radiating from the earth, dense clouds are formed, which shed their humidity in copious showers of rain.

directly under the sun, or possess extensive heated valleys and plains; and in consequence of the rarefaction of air over them are rendered more or less the centre of attraction for the surrounding atmosphere. The aërial masses on gaining such places of attraction can no longer move onward as surface winds, but being highly rarefied, are raised aloft and deprived of their moisture and borne away in upper air currents toward the regions from which they were first attracted. The rainy places thus created are constantly moving with the sun's declination over the lee shores of continents, causing rainy seasons; and at times gathering over mountainous districts because they assist in condensing the collected vapors. However, opposing winds may perform the same work in detaining vaporous winds and causing rainy places as mountain ranges.

On the tropical Indian Ocean the winds are largely swayed from following the direction of the sun's diurnal course, because of the attraction of the heated lands of Southern Asia. Yet on its off-shore waters south of the equator the winds pursue a regular course from east to west, wafting vapors sufficient to supply the great lakes at the head waters of the Nile and Congo. During the period of the monsoons, when the winds are turned alternately according to the seasons, from southern Asia to Southern Africa, the barometric pressure changes with the direction of the wind; the lowest pressure being to the leeward, near or at the termination of the periodical wind. These winds pay no regard to the equator as an attracting power, but blow towards regions where the heated atmosphere causes a low atmospheric pressure. The upper air currents of the monsoon regions have been found to move counter to the surface winds, having been sent aloft at the rainy terminal of the monsoon. For we are told that the monsoons which blow over Java have upper air currents which move the smoke and vapor of lofty volcanoes counter to the direction of the surface wind. Which fact goes to prove that the upper air currents are a continuation of the surface winds which have been raised aloft and deprived of

their moisture at the termination of the monsoon, and thus seeking an equilibrium over the places from which they were at first attracted. But it cannot be said that monsoons form at their terminals calm-belts of precipitation; for they end in more limited places even than the rainy regions situated to the west of continents. The southern monsoons which waft their vapors from the equator toward the heated shores of the Arabian Sea, on reaching such latitudes are turned by the attraction in front of the sun, which combines with the attraction of the heated shores of India to draw them towards the Ghaut range of mountains, where their vapors are mostly condensed and precipitated. But the next great rainy region to the westward is nearly three thousand miles distant, where the vapors gather over the great lake region of central Africa. Therefore the rainy regions of the tropics are far too broken and widely separated to represent calm-belts. In fact, all such rainy terminals of the winds of the torrid zone united would not reach one third of the distance around the earth.

The great Pacific Ocean affords a good example of the normal movements of the air-currents of the globe. On its eastern side against Central America we find a rainy calm centre with winds blowing towards it from the northward and southward, also light air-currents from the westward; the latter winds being caused by the attraction of heated lands combined with the attraction in front of the sun; while from the east vapors are received from the tropical Atlantic waters, being wafted by the easterly winds of that ocean. The air of this great rainy calm-centre being constantly rarefied by the heat of tropical lands, and by heat set free from condensing vapors, is carried to a great height, where it spreads out and cools, and then seeks to equalize the atmosphere through upper air-currents by returning to the regions from which it was at first drawn. This rainy wind centre, moving north and south according to the sun's declination, is never separated from the continent, and seldom extends one fourth of the distance across the Pacific: therefore, the winds which blow from the northward along the

coast of California and from the southward past the coast of Peru, do not all meet within its bounds, but are attracted westward by the daily passage of the sun over the sea, and by the heat carried in vapor by preceding winds and set free on the western shores of the Pacific, and also by the higher temperature of the western Pacific waters.

These great easterly winds thus following the several attractions caused by the daily passage of the sun over the ocean, are turned aside in places both to, and from, the equator through the attraction caused by the heated atmosphere over large groups of islands, where they often shed a portion of their moisture. But when the currents of air reach the western side of the ocean, they generally spread out, or unite with monsoons, being attracted by the heated lands of Asia, and Australia, and also by the warm waters which spread north and south from the torrid zone along the western borders of the Pacific. Still such portions of the easterly winds as do not turn away from the equator after crossing the sea, waft their vapors against the mountainous islands of the East Indies. This latter region then becomes a centre of aërial attraction for the surrounding seas, because of the heat set free from the condensing vapors. Consequently the same meteorological performances are carried on as represented in the rainy spaces to the west of continents. But such portions of the tropical surface winds as are turned away from the equator, on reaching the high latitudes assume a counter movement towards the east. This counter movement is probably gained in part because the high mountain ranges of tropical America bar the passage of surface winds from the eastward; therefore the cool air of the high latitudes is attracted down the coasts of North and South America, not only to furnish vapor for the rainy region against Central America, but these winds are the source of the great easterly winds which extend across the tropical Pacific Ocean. Consequently, through the great displacement of air in the high latitudes of the eastern Pacific, a westerly return wind is created to supply the aërial spaces thus vacated. And these westerly winds are probably

strengthened by the attraction in front of the sun, which being a concentrated force, holds its power on regions remote from the equator. Furthermore, the westerly winds are strengthened at times like the tropical winds, by the heat they convey in vapor to leeward lands. This heat, set free by condensation on the mountain ranges of Oregon, and Patagonia, no doubt gives strength to the westerly air-currents in the high latitudes of the Pacific in both hemispheres. In fact all winds are largely governed by whatever disturbing influence happens to be in or near their track. This we have shown to be the condition of tropical winds, while the westerly winds are still more subject to such influences.

The low atmospheric pressure so often occurring in places throughout the westerly wind-belts, is caused in the same manner as on the North Atlantic; that is, through the air being drawn from their latitudes over and along the western shores of continents, to supply the trade-winds and the heated regions on and abreast of tropical lands. Through this cause, combined with the attraction in front of the sun, the air rushes from the westward, over seas and lands, towards the low pressure areas until aërial equability is restored.

On the spaces of ocean which separate the easterly winds of the tropics from the westerly winds of the high latitudes, may be usually observed a high pressure of the air and fine weather; this is because the surrounding atmospheric disturbances are usually antagonistic and nearly equal. Such spaces having generally no overpowering attraction to govern the atmosphere over them, are still more or less subject to the invasion of the surrounding air-currents, which are frequently departing from their general bounds. And at certain seasons these regions of light variable winds and calms are crossed by furious gales and hurricanes, especially on their western portions where the atmospheric disturbances are somewhat frequent.

We have before denied that these regions of general high atmospheric pressure were bands reaching across oceans. Still, on the Pacific Ocean, as on the Atlantic, we find extensive regions of high barometric pressure situated

near the tropical zone between the central and eastern limits of the ocean, with air-currents frequently flowing from them towards the equator; but such spaces do not usually extend over one-half of the distance which separates the easterly winds from the westerly winds. Consequently, on the middle and western parts of the ocean the winds do not generally blow from the borders of the tropics towards the equator. Yet, according to Halley's theory, all of the easterly surface-winds of the tropical zone should meet near the equator and find their way to the high latitudes in upper air-currents. But the numerous observations of late years have shown that the tropical surface winds turn towards the high latitudes after passing westward of ocean centres; perhaps not always in a continuous course, but in a general way. For it is through this great movement of the tropical surface-winds that vapors are carried to furnish rain for the United States,* China, Japan, Eastern Australia, and the great plains of Rio de la Plata. And when we consider how the great rivers of these countries are fed by the moist winds which spread out from the tropics on the western sides of oceans, they appear amply sufficient to prove the general course of the surface winds of the torrid zone which so constantly enter the tropics on the eastern sides of the oceans. Still, such tropical winds as blow from the high latitudes and meet in calm rainy places are found to return in the upper atmosphere in counter-currents, as we have shown. But there is no evidence to show that such lofty air-currents convey sufficient moisture to supply rain to any country.

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* Lient. Maury, in his elaborate explanations of the atmospheric currents, was led through Halley's theory into the error of supposing that the vapors which produce rain over large countries situated like the United States, were taken from distant oceans in upper air-currents; because the theory he advocated could lead him to no other conclusion. But it is now beginning to be known that there is no land on the face of the earth but what derives the greater part of its rain directly through surface winds. The upper air currents which proceed from the rarefied air which ascends from the rainy regions, having already parted with the greater portion of their humidity and because of their thinness and low temperature, are in a poor condition to carry moisture to any country.

Yet when we consider how a large proportion of the air which enters the tropics on the eastern sides of the oceans is attracted westward, and becomes loaded with vapor while moving parallel with the equator and then turned toward the high latitudes to carry rain to the great countries above named, it is difficult to see how air so moving is left behind by the diurnal rotation of the earth. Sir John Herschel says, in his Treatise on Astronomy, "We have only to call to mind the comparative thinness of the coating which the atmosphere forms around the globe, and the immense mass of the latter compared with the former (which it exceeds at least 100,000,000 times), to appreciate fully the absolute command of any extensive territory of the earth over the atmosphere immediately on it in point of motion."

Accepting this fact, it does not appear that the air, even when moving over the earth's surface towards the equator, could be left behind sufficiently to create a north-east or south-east wind, much less an east wind which does not move at all towards the equator; neither could air-currents moving toward the poles so outstrip the speed of the earth as to create westerly winds. Besides this, how is such a theory to account for the frequent westerly winds which blow from the polar side of west? Moreover, as we have before declared, the solar heat which warms the seas of the equatorial latitudes is not sufficient to create a band of low atmospheric pressure around the earth, adequate to perform the great aërial circulation as described by Halley.

The test to be applied to every theory is its success in accounting for the facts which it was framed to explain. Therefore, after a long acceptance of Halley's theory for explaining the cause of the great prevailing winds, it is no wonder that writers acknowledge "that we look in vain for a direct manifestation of these laws which govern meteorological phenomena, and that dissatisfaction is frequently expressed at our imperfect insight into phenomena so varying and contradictory." Still, it is probably safe to say, that when the true cause of the great movements of the atmosphere is known, there will be nothing contradictory in their truthful explanation.

THE CAUSES WHICH PRODUCE THE GREAT OCEAN CURRENTS, AND THEIR EFFECT ON CLIMATE.

AMONG the vast operations of nature, the circulation of the waters of the sea is of great importance, because of its great power to moderate the climates of the different zones. For it is well known that the wide waters of the tropical latitudes move in large ocean streams, which send their strong currents far into the more northern and southern seas, thereby raising their temperature, while the cold waters of the polar seas send returning currents to cool the waters of the torrid zone.

To account for the manner in which nature works to perform this great task, has been the cause of much speculation. Early writers on the subject rightly supposed that the winds were the principal cause of ocean currents, but their knowledge of the winds and currents of the sea being necessarily limited, they failed to confirm their views; while the attention of the public was subsequently directed to the theories of ingenious persons who even insisted that wind had little to do with the general circulation of the waters of the sea, and that without wind there would be a perpetual and uniform system of tropical and polar currents, owing to a difference of density in the ocean waters, caused by a difference of temperature and saltness in the waters of the high and low latitudes; and also through disturbance caused by the rotary motion of the earth in connection with the above named influences.

The diurnal rotation of the earth in combination with great prevailing winds, is now regarded by persons of high authority on such matters as the main cause of ocean currents. But, while accepting such theories, they have

neglected to notice the full effect caused by great air-currents sweeping over oceans partly bounded by land. For when we consider their full potency, we find a simple and ample explanation for all of the great surface currents of the sea. And through them we also find an explanation for the great climatic changes, which during long intervals of time have passed over the high latitudes of the earth.

The waters of the North Atlantic offer a good field to illustrate these statements. The trade-winds which sweep over their tropical portion, while serving to supply the western slope of America with rain, are at the same time, with the assistance of strong westerly winds sweeping across their northern latitudes, forcing the waters of tropical seas through favorable channels far into the northern seas, thereby warming lands which, without such life-giving assistance, would remain cold and dreary regions. We see nature thus operating where tropical heat finds its way to high northern latitudes through that wonderful ocean current, the Gulf Stream.

Among the numerous and conflicting opinions that have been conceived concerning the cause of this great ocean stream, the theory advanced by Dr. Franklin, a few years after being informed of its existence by that observing old whaleman, Captain Folger, has long been considered by intelligent seamen as the most probable. Franklin, in his explanations of the Gulf Stream current, declared that it was occasioned by the constant trade-winds blowing the surface-waters of the tropical Atlantic into the Caribbean Sea and Mexican Gulf; thereby raising their waters above the common level of the ocean. And this is evidently one of the principal causes of its existence; but not the only cause. For the raised waters, without an easy channel to a lower sea-level, such as they now have for escape, would naturally return to the seas from which they were at first blown, through under-currents, when the heaped pressure became sufficient to cause them. But nature, in addition to the trade-winds, has made use of the great sweeping force of the westerly winds of the temperate zone; whose effects on

the waters of the sea have been only partially explained, even by those who recognize the winds to be the principal cause of ocean currents. In fact, they have always neglected to state the complete way in which the prevailing winds in connection with land circulate the waters of the sea. For this reason the westerly winds have not taken the grand position which belongs to them, as being the great mover of the North Atlantic and other ocean waters. Furthermore, the continued failure to recognize the main causes which move the tropical waters into the high latitudes, has been the occasion of obscuring the methods through which nature works to create such great climatic and geographical changes as have left their wonderful traces on the globe.

The strong westerly winds that sweep over the high latitudes of the North Atlantic, have the same effect as all other winds that blow over the water—that is, to blow its waters from the windward over to the leeward. These prevailing winds blowing over the yielding seas, create a low sea-level along the coast of America, extending from Cape Hatteras to Greenland; the waters abreast of the Banks of Newfoundland occupying the central portion of this wide depression. Consequently, the raised waters of the Gulf of Mexico find an easy outlet to this low sea through the deep passage around Florida. The tropical waters being warmer than the northern seas, do not readily mingle with them, but float over them. Moreover, the vast stream of waters on their northern passage are not arrested on the low sea-level, but retain through their force of motion somewhat of their northern course, while being gradually turned by opposing currents and prevailing westerly gales towards Europe, where they serve to warm the atmosphere of that portion of the globe. Yet, through their force of motion northward, combined with favoring winds on the north-eastern Atlantic, a portion of the waters are able to pass to the north of Europe and mingle with the arctic seas. Meanwhile, this immense flow of tropical waters northward receives great additions to its volume after passing the Florida seas, from the general high sea-level of the tropical Western Atlantic. But the

Gulf Stream is not the only current that is moving to fill the extensive hollow caused by prevailing westerly winds along the North American coast; for it receives a great current from the arctic seas, which moves down upon it from Davis Strait and the coast of Greenland, heavily freighted with ice to help fill its wide depression.

The strength of this arctic current is caused by the waters of the North Atlantic being forced eastward by strong westerly gales, through the wide seas between Iceland and Great Britain into the Arctic Ocean, causing a high level on the seas north of Europe and Asia. The narrow channel of Behring Strait, opening on a high level in the Pacific Ocean, only increases their elevation; while Davis Strait, opening directly on the low level of the north-western Atlantic, forms a convenient outlet for the raised waters of the arctic seas; in the same manner the Straits of Florida form the outlet to the raised waters of the Gulf of Mexico.

While considering the ability of the prevailing winds to do the work here ascribed to them, it is well to notice their great transfer power in the huge waves they constantly throw on the Atlantic shores of Europe, whose driving force on the west coast of Scotland ranges from six hundred to six thousand pounds to a square foot.

In tracing the whole round of the Gulf Stream and arctic currents, it will be seen that the westerly winds while driving the surface-waters of the Atlantic eastward, thus create a high sea-level against the coast of Europe; it is only such waters as pass to the north of the British Isles that are forced into the Arctic Ocean; while the heaped waters south of Ireland naturally return to the depressed seas caused by the trade-winds along the African coast, to be blown again into the Gulf of Mexico. Thus two great ocean currents are caused by strong prevailing winds; one encircling Greenland and the North Pole, and the other the Sargasso Sea and the large islands of the West Indies; the great circular arctic current being kept in motion by the ample force of strong westerly gales sweeping across the North Atlantic a distance of three thousand miles, causing, as we have shown,

a low sea-level along the North American coast, and a high level on the seas north of Europe, which proves sufficient to create a return current through the icy channels of Spitzbergen, and so down the east coast of Greenland to the low sea-level on the American side of the ocean. Yet at the same time, a large portion of the raised arctic waters pass around Greenland and the North Pole, through the seas and channels north of Asia and America, to gain the low ocean level on the western North Atlantic. In the lower latitudes, where the prevailing winds force the Atlantic waters around the Sargasso Sea and West India Islands, we see the vast waters circulated by two great ocean winds: viz., the trade-wind of the tropics blowing the waters west from Africa to Mexico, while the westerly wind forces them east in the temperate zone, the eastern and western portion of the ocean waters being moved mainly by the difference of sea-level caused by the above winds.

Although the Gulf Stream is one of the most constant of the ocean currents, owing to the uniform action of the Atlantic winds; still, it has long been noticed by seamen navigating its waters, that their general movement is greatly disturbed by only a partial break in the usual course of the prevailing winds. For example, an easterly wind blowing for a few days on the coast of the United States, has been known to reduce the Gulf currents to less than half of their usual strength and volume. Our nautical works tell us of adverse storms that have forced the Gulf Stream back to its sources, and piled up its waters to an elevation sufficient to inundate the Florida Keys many feet. And it is well known that the strong northern gales which at times sweep over the Mexican Gulf blow its surface waters out through the Yucatan channel, and so keeping back the waters of the Caribbean Sea which usually set northward; but when such winds cease, the waters rush back from the south toward the northern shores of the Gulf, so that its lower coasts and islands are inundated. Numerous facts could be named to show the power of winds to govern the motion of the waters of the sea. But such instances are too common and well

known to require extensive explanation. Thus it appears that ocean currents are necessarily somewhat variable in their force and volume, depending as they do on winds to give them motion. But their general circulation is never entirely arrested, because the varying winds are of short duration, and only act on portions of the extensive course of the prevailing currents. We know that the westerly winds of the North Atlantic often change from their general course; nevertheless their main sweeping force is from west to east; which the great ground-swell on the ocean in their latitudes forever indicates.

In estimating the ability of winds to cause and govern the great currents of the sea, through their wide sweeping force, we should notice their constant transporting of water in vapor as adding considerable additional power to air currents for producing inequalities of level on the ocean's surface. The winds which push the surface water of the sea away from continents, causing depressed sea levels, are from the land. Therefore they are dry winds, and in a condition to cause a rapid evaporation. We see this illustrated where the dry dusty winds on the African side of the tropical North Atlantic maintain a rapid evaporation, which gradually decreases in their sweep across the ocean. Consequently, when they reach the West India seas and the watersheds surrounding them, the precipitation is probably much greater than the evaporation. Still this minor tendency of the wind for circulating the ocean waters mostly acts in unison with its sweeping force. Yet when we consider the great amount of water evaporated from tropical seas, which is borne by the winds to the high latitudes, we can realize the source of the great glaciers which are constantly forming in the polar regions. Moreover the waters thus taken from the equatorial regions, combined with the great amount of tropical water forced toward the poles by prevailing winds, in the manner we have shown how the Gulf Stream is forced northward, causes in many parts of the sea a slow undercurrent to set from the high latitudes toward the equator.

Writers have endeavored to explain the cause of such

ocean currents, through the effect produced by a difference of density in the waters of the sea, in consequence of their difference in temperature, and also through their difference of saltness which is said to exist between the poles and equator; but it is now estimated that such differences are nearly equal and quite antagonistic.

The earth's rotary motion, so often declared to influence the direction of winds and ocean currents, fails to show its power over the movements of ocean waters in places of extraordinary facility for such an exhibition. To confirm this statement, attention is called to that portion of the equatorial current which turns south near Cape St. Roque, and continues on a southerly course along the South American coast direct for a low level of the ocean against Patagonia, This depression is caused by the westerly winds blowing the waters away from the eastern shores of South America; consequently the ocean waters perform a journey of over two thousand five hundred miles in direct opposition to the diurnal-rotation theory, in order to gain a low portion of the ocean, which is lowered sufficiently by prevailing winds to attract the antarctic waters from the south beyond Cape Horn, as well as the equatorial waters from the north to fill its depressed condition. The Mozambique current is another refutation of the rotary theory. This vast movement of tropical waters along the eastern coast of Africa towards the southern ocean is caused by the prevailing easterly winds which force the waters of the tropical Indian Ocean against the African shores, so they escape from their high level through the Mozambique Channel; but after passing Madagascar they do not turn toward the east until forced in that direction by the strong westerly winds of the southern ocean; but follow the coast in a south-westerly direction, a portion of them at times even passing around the Cape of Good Hope when the winds permit, to gain a low sea level caused by the south-east trade-winds on the south Atlantic. In fact but a small portion of the circulation of the world's waters can be explained by virtue of the earth's rotation, as now set forth in our text-books; while the effect produced

by winds blowing over the sea everywhere proves them to be the main cause of ocean currents. Still the rotation theory seems to have more effect on many ingenious minds than the rotation itself ever had on objects moving on a line with the meridian north or south. Long experience has yet failed to teach the watchful mariner, while steering a due north or south course with a west wind, on the Atlantic or other seas, to make allowance for the earth's rotation; but for the winds and waves he always makes deductions, more or less, according to their force. And he also finds that the average leeway is the same on the southern course as on the northern, —a fact which could not happen on the ground of such potent swaying power as has been ascribed to the diurnal rotation of the earth.

While considering the ocean currents, it will be seen that the North Pacific waters have little to do with the circulation of the arctic seas, because of the nearly uniform level of the two oceans at Behring Strait. Moreover, the circulation of the Pacific waters affords no perfect comparison to the currents of the North Atlantic, owing to geographical differences: yet they are produced by the same natural agents. The Japanese current, having no land-locked sea to give it head, is consequently less concentrated in its movements than the Gulf Stream. The East India seas, having numerous channels opening on the low level of the Indian Ocean, a portion of their heaped waters created by the prevailing winds of the tropical Pacific are drawn in that direction, instead of their wide volume being attracted to the depressed seas caused by the westerly winds which blow over the Japan waters. Thus it happens that the great circular North Pacific current, although enormous in its movement, is constantly weakened in its course. For this reason the seas north of Japan, owing also to extensive land obstructions, are mostly excluded from its warmth; and even on the shores of Alaska it is said that glaciers reach the tide-water.

Among those who have endeavored to solve the cause of the great North Atlantic currents, we find that Lieut. Maury has given them much attention; and, while attempting to ex-

plain them, says, "If the Gulf Stream is caused by the trade-winds, where are the winds that give the high level to the waters of Baffin's Bay, or even press upon or assist to put the great arctic current in motion?"—and failing to discover such winds, was driven to the conclusion that "winds have little to do with the general system of aqueous circulation in the ocean." Meanwhile, if he had noticed the immense power of three thousand miles of prevailing westerly gales sweeping out of Davis Strait across the arctic borders of the Atlantic, and after passing Iceland gradually sweeping the surface waters toward the seas north of Europe, he would have seen a force amply able to give motion to the appendant and somewhat limited arctic seas. *

To show the universal action of the wind in connection with land on the waters of the earth, brief notice will be called to all of the principal high and low sea-levels on the globe, including those which have been mentioned. The prevailing westerly winds of the northern temperate zone, as we have shown, produce a depressed sea-level along the eastern shores of Asia, and along the eastern shores of North America; consequently we find a high sea-level against extensive lands under their lee, such as are maintained against the Atlantic shores of Europe, and the Pacific shores of America north of Mexico. In the torrid zone we find the prevailing easterly winds creating depressed sea-levels on the Atlantic, along the western coasts of northern and southern Africa, and their opposite high sea-levels on the lee shores of tropical South America and Mexico. On the

* The great arctic current, a portion of which surrounds the north pole, has caused the loss of several ships from our whaling fleet within a few years. These vessels, after being beset by the ice-fields of the polar seas north of Behring Strait, could not be saved because of the north-east current which swept them with the ice into the frigid seas north of North America, to undergo destruction before reaching the common destination of floating ice on the low level of the Atlantic abreast Newfoundland. Such being the tendency of ocean currents in the seas north of Behring Strait, it may follow that the exploring ship Jeanette now in that region, if beset by ice, would be currented like the lost whalers to the north-east toward the pole; from which position an escape would be extremely difficult.

tropical Indian Ocean we find a depressed sea to the westward of northern Australia, and a high sea-level on the African side of the ocean, which sends an immense current to the south—its main point of escape to the general level of the Southern Ocean. On the tropical Pacific we find a low sea-level abreast of Peru and Mexico, and a vast high sea-level on the leeward side of the ocean against the East India Islands. This great high ocean-level sends off its heaped waters to the south along the eastern shores of Australia, and to the west through Torres Strait and other India passages to the low level of the Indian Ocean; and a northern current to the depressed seas abreast Japan.* The great belt of westerly winds sweeping the southern seas, produces comparatively few inequalities on the ocean's surface, from the lack of obstructing lands. Yet, we find where the southern lands of South America partly cross this great wind-belt there is maintained a high sea-level against its Pacific coasts, and a depressed sea-level along its Atlantic shores. Other lands penetrating this zone of westerly winds, lack extent, or are too broken for the winds to cause great and constant inequalities on the ocean's surface. But its single great high sea-level against the Pacific shores of Chili, extending to Cape Horn, sends a vast cold current upon the depressed seas against Peru. This mighty rush of cold water from the main high level of the southern seas, upon the great low level of the tropical Pacific, lowers the temperature of the latter sea many degrees, so that the Galapagos Islands, on the equator, have a colder sea than any other tropical islands.

The low sea-level on the South Atlantic west of Southern Africa—caused by the southeast trade-winds—attracts cold water from the common level of the Southern Ocean; and it also attracts a portion of the warm waters of the Mozam-

* While describing the several great sea-levels of the ocean, it is well to note that the rainy tropical seas lying against the western shores of continents probably maintain a higher level than the seas surrounding them; because of the great fall of rain in such regions, and also on account of their being places of attraction for extensive surface winds.

bique current after it has passed to the south of the Cape of Good Hope. Through this cause, the waters of the tropical Atlantic are not cooled so extensively as the tropical Pacific waters are cooled by the Peruvian current. And it is because of this warm current running from the Indian Ocean into the Atlantic, that the considerably limited tropical waters of the latter ocean are able to maintain the present high temperature of the Gulf Stream. Furthermore, this flow of water around Southern Africa is in direct opposition to the rotary theory, as we have before explained.

Although the great high and low sea-levels of the Indian Ocean are more governed by the changing monsoons than the waters of other oceans; still, on its wide tropical seas south of the equator is found a constant easterly wind, causing a low sea-level on its eastern side; which attracts the warm waters of the high level of the tropical Pacific through Torres Strait and other East India channels. Consequently, comparatively less of the cold Southern Ocean water finds its way into the Indian Ocean than is drawn into the Atlantic and Pacific Oceans. Therefore, the Indian Ocean waters have a higher temperature than other tropical seas. Moreover, in consequence of the limited but direct passage of the waters of the high level of the tropical Pacific to the low level of the tropical Indian Ocean, the equatorial current of the former ocean is generally much stronger than the equatorial currents of other oceans. From this brief explanation it will be seen that the great high and low sea-levels of the globe are caused and governed by the position of continents, and the force of prevailing winds blowing to and from them over the sea; for when the winds blow the surface waters away from a continent, the depression thus caused affords a high sea-level against an opposite shore. Therefore in connection with land barriers, the great counter wind-belts of the globe are continually causing unevenness on the ocean's surface, sufficient to mingle the waters of the different zones. And it is through such means the tropical waters are able to reach the high latitudes, and thus raise the temperature of regions which otherwise would remain intensely

cold. Still, writers on this subject have always neglected to state how this important fact is accomplished. They never explain how the Gulf Stream is attracted north along the American coast, because the waters have been lowered by the force of prevailing westerly gales; for it is only through this means that the tropical waters of the West India seas are enabled to reach high northern latitudes. And while the warm waters are being drawn to the low sea-level, the westerly winds are drifting them eastward and covering the North Atlantic with their warmth, and consequently raising the temperature of extensive northern regions above the freezing point. Therefore, were the raised waters of the Gulf of Mexico not thus attracted to northern seas, they would return to the low sea-level of the African coast from which they were at first blown by the trade-winds, without entering the cold northern latitudes, and thus deprive Europe of its mild climate. Hence the temperate climate of Europe depending entirely on the warm waters of the Gulf Stream reaching the high latitudes through the regularity and force of winds, any unusual change in the strength and direction of these winds must cause a corresponding change of climate in the regions under their influence.

In this way we account for the exceptional cold winters of Europe spread over so many centuries. For when northern winter gales blow from an unusual direction, and force the warm Gulf waters largely away from their general northern course, the temperature of the northern regions is naturally lowered in proportion to the heat thus turned away from the high latitudes. But the brief and exceptional spells of cold weather so caused, are of little account compared to the great and prolonged climatic changes which have at wide intervals passed over the northern temperate zone. For we have abundant geological evidence of great ice periods, and intervening eras of mild weather, having been maintained on the now temperate countries of northern Europe and America. Such changes would naturally be effected by the common workings of nature as carried on to-day. Thus a cold period would gradually be brought about, such as is

now taking possession of lands situated in high northern latitudes, through the independent circulation of the arctic seas. The channels which now lead into Davis Strait afford a passage for the waters of the high sea-level which exists to the north of Europe to the low sea-level abreast Newfoundland. This difference of ocean level being created by strong westerly winds—as we have before explained—consequently the rush of cold water through Davis Strait tends to force the Gulf Stream southward, and also to cleave its waters from the American coast, so that its harbors have colder water than any other region in the same latitude on the globe. And it is probable that the arctic channels are slowly enlarging their capacity through the scouring of icebergs, and thus swelling the volume of the arctic currents sufficient to force the tropical waters further southward, and so increasing the independent circulation of the arctic waters, and in this manner gradually lowering the temperature of northern regions. The reason why we suppose nature to be so operating, is on account of the growing coldness of lands situated in high northern latitudes. For there is no doubt that more snow falls on such lands in winter than is melted during summer. Therefore, the heat which finds its way northward from tropical seas, is being gradually overcome through the accumulation and spread of cold in the shape of snow and ice. Consequently, in addition to the gradual retreat of the tropical waters from northern seas, the wide accumulation and spread of snow and ice over northern lands constantly destroys the power of the sun for heating such lands, because the conditions necessary for receiving and radiating solar heat are being gradually lost on account of the spreading snow. The historical evidences of Greenland and Iceland possessing a mild climate seven centuries ago, shows that there has been some cold agent acting on those regions since that time. The climate of Northern Europe has long been accused of growing colder. For we are told that in Sweden spring commences fifteen days later than it did in the last century; the vine no longer flourishes on the shores of Bristol Channel, or in Flanders, or Brit-

tany; and vineyards are no longer planted on the elevated lands of France where they flourished three hundred years ago. Hence, there seems to be no lack of historical evidence to show the general growing coldness of Northern Europe. The frequent failure of the more hardy cereals during recent years, also reveals the growing inclemency of its climate. As all great changes of climate are necessarily slow, the lowering temperature is scarcely perceptible to a single generation. Yet, when we consider how nature works to produce such great climatic changes, it appears that the cold must continue to increase so long as the Gulf Stream receives no greater supply of heat than now, and the waters of the arctic seas have a free passage through the channels leading to Davis Strait, by which means the cold waters are enabled to force the Gulf Stream southward, and so preventing the tropical waters from reaching the northern seas. These deep channels circulating arctic cold will be slow to close, because the surface ice acts as a shield to the deep waters beneath. We know that the cold of winter does not seem to weaken the polar currents running through them; for they succeed in the winter season, with the help of northwest gales, in forcing the surface waters of the Gulf Stream over ten degrees further from Greenland than they do in the late summer months.

The only way of arresting the increase of cold with such an amount of heat as the tropical Atlantic can afford the Gulf Stream at the present time, would be through the slow process of glacial action in the vicinity of the arctic straits. For should the glaciers of North America, accumulating on extensive lands sloping northward, obtain sufficient thickness to give them irresistible motion towards the northern straits, the process of closing them would be comparatively short and effectual. This being completed and the independent circulation of the arctic waters arrested; the high sea-level of the western tropical Atlantic and Gulf of Mexico would be the only water to seek the low sea-level along the American coast. This warm water meeting with no opposition from polar currents, would wash all the

shores and harbors of North America from Florida to Greenland. Such flowing of tropical waters northward would probaby check the further accumulation of ice in the northern hemisphere, and also maintain a temperate climate of long continuance over northern Europe and Siberia. The centre of polar cold during such a period would be confined to the great ice-sheet blocking the arctic channels. For the immense glacier closing them would extend southward to the headwaters of the great Mackenzie river; and being favorably located to receive and retain the snow created from the vapors of the North Pacific Ocean through a long period, it would under such conditions be the most massive sheet of ice that could form on the northern hemisphere. Hence, owing to its cold location and immense extent, it would require a long time to free the arctic channels which now give a partly independent circulation to the northern seas, and consequently serve to lower the temperature of a large portion of the seas and lands situated in high northern latitudes.

But when we consider more widely the oceanic changes that must have occurred during the perfection of the greatest ice periods which have taken place in the northern hemisphere, we find other sources of heat added to the Gulf Stream which would be sufficient to rapidly melt the most extensive ice-sheets that could form in the northern latitudes. For, when the southern hemisphere became largely free from ice,* the earth's centre of attraction would be moved northward at the culmination of a northern ice period; consequently the waters of the southern seas would follow such attraction. Therefore, the low lying lands of northern Africa would not present the effectual barrier they now maintain against the heated waters of the tropical Indian Ocean. We now see the great equatorial current of the Pacific Ocean extending through the East India straits and joining the equatorial currents of the Indian Ocean,

* We allude to ice periods having occurred in the southern hemisphere as well-established facts which we shall presently explain.

and on reaching the African coast turned away toward the great southern seas, where only a small portion of the waters are able to pass around the Cape of Good Hope into the Atlantic because of the westerly winds. Yet there is ample geological evidence to show that the low lying desert lands of northern Africa have been covered by the sea. Consequently, during such a period the great tropical currents of the Pacific and Indian oceans, instead of being turned toward the southern seas, would continue on through the shallow seas of northern Africa and unite with the tropical currents of the North Atlantic. The waters from the Indian Ocean would add considerably to their high temperature while being urged by warm prevailing winds along the shallow seas of Sahara to the low sea level of the North Atlantic. During the summer season the strong southerly monsoons which now force the warm waters of the Indian Ocean into the Red Sea, would, with the low lands of Suez submerged, force the tropical waters well into the Mediterranean, and so raise its waters sufficient to cause a strong current to flow through the Straits of Gibraltar into the Atlantic. Yet it is probable that the Straits of Gibraltar would not be the main channel for the Indian Ocean waters, because of its opening on a somewhat high level of the Atlantic; and also being situated north of the favoring tropical winds. Therefore the waters from the Indian seas would find a more favorable channel south of the Atlas range of mountains, which would be more in line with the equatorial winds and currents. The great low level of the tropical North Atlantic being situated between the Canaries and Cape Verde Islands, we also find the most depressed portions of the great desert abreast those seas. For it is reported that extensive tracks of land in this region are even now below the level of the ocean. Hence it appears that when the low lands of Egypt and Sahara were submerged, the North Atlantic must have been the receptacle for a large portion of the conserved heat of the torrid oceans of the globe. The Gulf Stream thus greatly enlarged and possessing the highest temperature to be attained from

tropical seas, would carry ample heat into the high northern latitudes to subdue their frigid climate. And when we consider that the low lying lands of the northern hemisphere were submerged during the breaking-up of great ice periods, therefore at such times the warm gulf waters must have flooded the whole Mississippi valley. And while the vast ice-sheets melted away, the warm waters extended over the great lake region; the wide shallow seas opening even into Hudson's Bay. The winds during such periods prevailing as now, would sweep from the trade wind region over the Gulf of Mexico, and from thence up the Mississippi valley, thus assisting the tropical currents on their way to the low sea-level of the North Atlantic, which would be extended to Hudson's Bay. The gulf currents under such conditions must have gained a much higher latitude than they now reach; therefore their high temperature penetrated far into the arctic seas.

The warm surface waters blown toward northern Europe would not only melt the ice from its lands, but such conditions would give warmth to the wide shallow seas which during such eras must have covered all the low lands of that extensive region. The vast marine deposits which are found embedded in the low lands of Europe attest the warm temperature of the ancient seas. Thus, when we consider the geographical conditions of such periods, it appears that the conserved heat of the tropical Pacific, Indian and Atlantic Oceans, added to the gulf currents, must have carried sufficient heat into the high northern latitudes to subdue the arctic cold, however wide its extent.

During the submergence of the low northern lands, which must have continued as long as the southern hemisphere remained free from ice, the high sea-level of the North Atlantic would be maintained by the westerly winds on its leeward portion; which embraced the shallow seas which covered all the low lands of northern and western Europe. Although this vast high sea-level of warm water found a limited outlet through the straits now leading out of the Black Sea, yet the high sea-level would be maintained

so far eastward against Siberia, it is probable that a strong current run out of Behring Strait to the low sea-levels of the North Pacific Ocean; from whence the waters were formerly driven by the prevailing winds along the tropical zone into the Indian Ocean, and from thence through the Sahara Seas into the North Atlantic, and so onward by the Gulf Stream, returning again to the arctic seas. In this vast movement of ocean waters around the eastern continent, it will be seen that three-fourths of the distance would be performed under the tropical winds; in fact only one-eighth of this great circular current would pass through the arctic seas.

We have alluded to the ice periods of the southern hemisphere because it presents the same geological traces of great climatic changes as the northern latitudes. The islands and shores of Patagonia and New Zealand show ample traces of ancient glaciers. Kerguelen Land shows traces of having passed through great changes of climate. At present it is too cold to support even a shrub; yet, abundant fossil remains prove that its lands were once covered with forests, which serves to show that its shores have been washed by the tropical waters of the Atlantic and Indian Oceans. This land also has the appearance of having passed a period of far lower temperature than it now possesses, although its cold climate even now makes it a land of desolation. Yet those climatic changes have evidently been produced by the slow and constant operations of nature now in force.

The lands of the antarctic circle, now heavily capped with ice, will probably long remain loaded with glaciers, because of the independent circulation of the waters of the southern ocean. For so long as such conditions exist, the climate of high southern latitudes must be gradually growing colder. To accomplish this work, the westerly winds are continually blowing the surface waters of the southern seas from west to east around the earth. Therefore the tropical waters blown against continents by the easterly winds, find no attractive low sea-level in the southern westerly wind-belt

sufficient to draw them far into the southern seas. It is generally known to navigators that the great surface currents of the southern ocean, between the latitudes of 40° and 60°, form an effectual barrier or "cold wall" to the further progress southward of the equatorial surface currents. Consequently the antarctic ice-cap is constantly increasing its dimensions, and this lowering temperature will probably continue until the great southern ice sheet closes the channel connecting the Atlantic and Pacific oceans south of Cape Horn. The deepest portion of this comparatively narrow strait is flanked on the north and south by shallow waters extending east and west over a thousand miles; and when we consider the immense fall of rain and snow on the lands of these regions, which exceeds that of all other parts of the globe excepting a few tropical places, it will be seen that the glaciers which have already appeared in the Southern Andes will, with a somewhat lower temperature, rapidly cover the plateaus of Patagonia and Chili, and even push out into the shoal waters extending beyond the Falkland Islands, towards the east, and to a considerable distance westward in the Pacific Ocean. Therefore, the glaciers from South America will in time unite with the great southern ice-cap, and thus close the Cape Horn channel. This being effected, the westerly winds of the southern hemisphere, sweeping over the southern ocean, would cause an extensive low sea-level to the leeward of the great ice barrier. This vast low sea-level would extend eastward considerably beyond the meridian of the Cape of Good Hope, and consequently would attract the warm waters from the high sea-levels of the tropical Atlantic and Indian oceans, well into the southern seas; when the great process of melting the vast antarctic ice-sheet would commence. And this process would be considerably rapid with the great tropical currents of the globe turned against it. Yet the great ice-barrier connecting South America with the great antarctic ice-cap would be slow to melt away, on account of the frequent snow storms of that region, and because of its being situated to the windward of the tropical currents. The currents of air and water

approaching it from the westward would lose much of their warmth during their long sweep along the ice-sheets lying south of the Pacific and Indian oceans; besides, it should be considered that the upper portions of the great ice barrier would be so much elevated above the ocean that only such parts as lie next the sea would be liable to thaw; moreover the polar cold, on being subdued southward of the Atlantic and Indian oceans, would centre over the great ice-barrier, because of its comparative inaccessibility to the warmth of the tropical surface currents; therefore this ice-barrier would be the most enduring ice in the southern hemisphere.

The great southern ice-cap now extending, and destined in time to close on the southern extremity of the western continent, and thereby, through a simple process of nature, shaping its own destruction, is constantly, from its vast increasing dimensions, attracting so much of the waters of the globe towards it as is required to harmonize with the earth's changing centre of attraction. Consequently, many of the shoals and banks covered by the seas of the high southern latitudes are drowned regions, so that the islands of those waters have the appearance of being partly submerged.

Although this tendency of water southward will probably be checked somewhat by the accumulation of ice on Greenland and other arctic shores, still the great extent of southern seas where vapors form to be changed into ice, being superior to the northern waters, it is probable that the southern lands will be subject to yet further submergence.

The changing conditions of seas and lands, which must have taken place through the different stages of cold and mild periods, are a subject of great interest. The solid parts of the globe, such as continents, islands, and extensive shoals, and deep sea basins, being slow to change their general form, we can conceive some of the principal alterations which must have occurred in the geography of the earth, with a considerable portion of the ocean waters stored in the form of ice around the poles, or changed from one pole to the other. Thus, should both hemispheres be iced at the same

time, the ocean waters would necessarily be at their lowest stage in the torrid zone, because of the immense amount of water stored in the great polar ice-caps. But should the northern and southern regions be mostly free from ice at the same time, the ocean waters would correspondingly deepen at the equator. In such an event, the low-lying lands of the torrid zone would be flooded. Yet it is obvious that the equatorial latitudes are not as subject to great submergences and uprisings as the high latitudes. For, should the high southern latitudes be loaded with ice, and the northern regions be comparatively free from frost, the southern regions would probably undergo a great submergence.* While, on the other hand, should the antarctic regions be mostly free from ice, and the arctic regions burdened with it, the ocean waters would be attracted towards the northern latitudes. Although we now see the ice accumulating in the high latitudes of both hemispheres, it is not likely the ice periods of the north and south will culminate at the same time; because the different geographical construction of the hemispheres is not favorable for it. Furthermore, it appears that when the great tropical currents are turned largely into the high latitudes of a hemisphere—through the causes we have explained—it is evident that the tropical currents entering the high latitudes of the opposite hemisphere would be proportionally lessened; therefore, the process of melting the ice-caps of the different hemispheres would occur more or less alternately. Still, both hemispheres might be heavily iced before the combinations necessary for melting the ice-sheet from the southern hemisphere could be brought about. Consequently, at such times the tropical oceans would be considerably absorbed by the great gathering of ice around the poles. And when we

* While considering the great changes which have occurred in the ocean's level, we can conceive how the South Sea Islands have become peopled by men who seemingly had no adequate means of reaching such insulated parts of the globe as they have been found to inhabit. For it now appears evident that such detached shores have not always maintained the wide separation from other lands they now possess.

consider the great submergences of land which have occurred in the northern latitudes, it appears that they must have happened while such lands were burdened with ice, and the antarctic regions were mostly free from it. The earth's centre of attraction having in consequence moved northward, the waters melted from the southern ice-cap would be free to follow such attraction. We have stated, how, during such an event, the waters of the Gulf of Mexico would be greatly extended ; consequently, the seas which would cover Florida and all the low lands of eastern North America would be moved by warm ocean currents on their unobstructed way northward, along the low sea-level created by the westerly winds. And when we consider that the low lands of northern Africa would be submerged, and consequently the great tropical currents of the Pacific and Indian Oceans would find their way directly into the North Atlantic, we can well account for the heat which would melt the great northern ice-sheet, and raise the temperature of the whole arctic region. For under such geographical arrangements the North Atlantic and Arctic seas would be the reservoir for a large portion of the conserved heat of the tropical waters of the globe. During such a period, the southern hemisphere would gradually lower its temperature because of the equatorial waters being turned into the arctic regions. And when the lands of the northern hemisphere became free of ice, the growing ice-sheet of the antarctic regions would in time drain the Sahara seas, and so cut off the great tropical currents from the arctic waters, so that ice would again gather on the northern shores and thus create the climatic conditions which are mantained to-day. But the coldest period of the north would probably occur while the process of melting the southern ice-sheet was being carried on, because during such a period the tropical currents of the Atlantic would be more largely drawn into the great low sea-level of the southern ocean.

Ever since the existence of ice periods has been geologically proved to have possessed the high latitudes at wide intervals, and separated by eras of temperate weather, va-

rious theories have been advanced to explain their cause, and besides to account for the great submergences and upraisings of low-lying lands. Some writers have imagined that a change in the position of the earth's axis of rotation, due to the elevation of extensive mountain tracts somewhere between the poles and the equator, must have caused the great climatic changes which have left such abundant traces on the globe. But it has been proved that the protuberance of the earth at the equator so vastly exceeds that of mountain ranges or table lands on the globe, that only slight changes could have resulted from such causes. It has also been considered that during the ice period the lands in high latitudes of the northern hemisphere stood at a higher level than at present, and consequently became iced like the highest mountains of the present time. But there is no proof that the lands attained a much higher altitude or covered a much wider era than now; on the contrary, all evidence goes to show that large tracts of low lands in the northern hemisphere were submerged during the ice period.

The theory so ably explained by Sir Charles Lyell was for a time favorably received. Lyell conceived that if lands were massed chiefly in the tropics, the climate of the globe would be such that tree-ferns might grow luxuriantly on any islands that might lie within the arctic or antartic circle. For he supposed that the heated lands would give rise to warm winds which would sweep north and south, carrying with them the heat of the tropics, and thus temper the climate of the higher latitudes. On the other hand, were the lands to be grouped chiefly around the poles, the reverse of all this would happen. For with no land under the equator to receive the heat of the sun and give it to the winds to carry north and south, the climates of the high latitudes would be so greatly affected that snow and ice would gather npon the ground and gradually creep down to the lower latitudes. Thus the atmosphere is represented to be the chief medium by which heat derived from the sun is carried from one latitude to another. This explanation has been generally abandoned; because, after a regardful

examination, ocean currents, although caused by winds, have proved to be the great carriers of heat from the tropics to the high latitudes. Moreover, there is nothing to show that there has been any great change in the position of continents during the periods of frigid and mild temperatures which have been maintained in the high latitudes. Professor James Giekie, in his lectures on climatic changes, says, "It is quite certain that no one can show that our glacial climate was induced by any peculiar arrangement of land and sea." This statement was intended to show that there had been no great changes in the situation of continents and large islands, and is not antagonistic to the explanations we advance; on the contrary, the interesting facts promulgated in his writings on climatic changes have been a valuable aid while considering the explanations here given.

Professor Tyndall, while alluding to the great ice-age, says, "I have no new hypothesis, but it seems possible to give a truer direction and more definite aim to our inquiries. The aim of all writers on this subject with whom I am acquainted, has been directed to the attainment of cold. Some eminent men have thought, and still think, that the reduction of temperature during the glacier epoch was due to a temporary diminution of solar radiation; others have thought that in its motion through space our system may have traversed regions of low temperature, and that during its passage through those regions the ancient glaciers were produced; others, with greater correctness, have sought to lower the temperature by a redistribution of land and water. For to create glaciers requires the operations of heat as well as the arctic cold." Thus it will be seen that the statements of this learned Professor are in harmony with the explanations we have given, and are regarded as one of their firm supports.

One of the latest and most deeply studied, and widely accepted theories which have been propounded to account for the great climatic changes which have taken place on the earth at wide intervals, is by Dr Croll, a high authority on the subject, who gives this explanation. "When the eccentri-

city of the earth's orbit is at a high value, and the northern winter solstice is in perihelion, agencies are brought into operation which make the south-east trade-winds stronger than north-east, and compel them to blow over the northern hemisphere as far probably as the Tropic of Cancer. The result is that all the great equatorial waters of the ocean are impelled into the northern hemisphere, which thus, in consequence of the immense accumulation of warm water, has its temperature raised, and snow and ice to a great extent must then disappear from the arctic regions. When the precession of the equinoxes brings round the winter solstice to aphelion, the condition of things on the two hemispheres is reversed, and the north-east trade-winds then blow over upon the southern hemisphere, carrying the great equatorial currents along with them. The warm water being thus wholly withdrawn from the northern hemisphere, its temperature sinks enormously, and snow and ice begin to accumulate in the temperate regions. The amount of precipitation in the form of snow in temperate regions is at the same time greatly increased by the excess of evaporation in low latitudes, resulting from the nearness of the sun in perihelion during summer. The final result, therefore, is that those warm and cold periods which have alternately prevailed during past ages, are simply the great secular summers and winters of our globe, depending as truly as the annual ones do upon planetary motions."

However ingenious and plausible this theory may appear, and widely accepted by persons interested in such matters, it is not in harmony with well known natural laws, or with historical records of climatic changes. Eminent astronomical writers have stated that no appreciable change of climate could possibly result from any variation in the eccentricity of the earth's orbit. The earth, they maintain, receives the same total amount of heat in the aphelion as in the perihelion section of its orbit. This we know is due to the fact that our globe moves with less speed at aphelion than it does in perihelion, therefore in aphelion the greater distance of the earth from the sun is exactly counter-balanced by the

longer time the globe is exposed to the solar rays. Consequently it does not matter to what extent the eccentricity of the orbit may vary; the equal distribution of the sun's heat must continue invariable. And it is generally acknowledged that these arguments strictly agree with well ascertained facts, and cannot possibly be controverted.

Therefore Dr. Croll's explanations cannot be accepted, while we realize that the tropical waters receive constantly the same amount of heat from the sun's rays. Besides, it would not seem possible for the trade-winds to blow the equatorial surface waters over to the tropic of cancer, with a vertical sun at perihelion in the southern hemisphere. The great tropical wind-belt is well known to be governed largely by the sun's declination, and it seems certain that solar heat would lose none of its power for controlling the winds with the sun at perihelion. Hence it appears that it would be impossible for the tropical winds to blow the equatorial surface waters wholly into either of the hemispheres. Moreover, Dr. Croll asserts that the ice periods of the northern and southern latitudes occur alternately; consequently the ice-sheets of the northern hemisphere would have to be melted by the sun's rays alone before the temperature could be raised sufficiently to attract the tropical winds northward, and impel the waters into the northern seas. Such conditions would impose too great a task for the sun's rays to perform in the high latitudes, without first having assistance from the heated waters of the tropical oceans.

We have before explained that there is apparently only one effectual way through which nature forces the currents of the sea with sufficient rapidity from one zone to another, so as to change their temperature to any great degree; such work being accomplished through great prevailing winds blowing the waters of the different zones to and from continental barriers, and thereby changing the level of the sea sufficient to cause great surface currents to run from one zone to another, in the manner we have pointed out, as being carried on in the northern and southern hemispheres. We think that Dr. Croll rightly assumes that the winds are the

principal cause of ocean currents, and also that they are not due to the trade-winds alone, as was recently supposed by the advocates of the wind theory, but to the general impulse of the prevailing winds of the globe.

Dr. Croll also declares that "all the principal currents of the globe are moving in the exact direction which they ought to move, assuming the winds to be the sole impelling cause." This general agreement between the system of winds and of great ocean currents he illustrates on a chart. But the direction of winds as laid down on this chart does not correspond with the well-known prevailing direction of winds which blow over the Atlantic from Florida to Labrador. According to Dr. Croll's showing, the Gulf Stream is impelled along the shores of the United States by a prevailing wind blowing its waters along, in the same manner that the trade-winds force the tropical Atlantic waters from Africa to Mexico. But this is not so in any great degree; because the trade-winds which blow the tropical waters from Africa over towards Mexico do not generally turn north with the Gulf Stream along the shores of the United States—their irregular northern movement being largely diffused over the great Mississippi Valley until they blend with the great westerly wind-belt of the high latitudes. Consequently there is no prevailing wind blowing the Gulf waters from Florida to seas abreast Newfoundland. On the contrary, the strong westerly winds which have the most effect on the western Atlantic waters are from the north of west. They merely blow the surface waters away from the American coast, so that the waters of the high sea-level of the Gulf of Mexico are attracted along the shores of the United States, because of the low sea-level occasioned by the westerly winds. Still, the westerly winds do not force the waters away from the American coast continuously, in the manner the trade-winds are seen to force the tropical waters away from Africa; for the westerly winds blow by spells; and it is because of intervening lulls, and the changing of the winds, that the Gulf waters are prevented from being blown much further from

the coast than they now are found. The great stream of Gulf water during the intervals of light or varying winds, is attracted directly along the low sea-level of the Atlantic, where not crowded off by the arctic currents, so that the strong westerly gales can only drive its surface waters eastward. Still, as we have before stated, the strong winter gales, with the help of arctic currents, do force the surface water of the Gulf Stream eastward hundreds of miles away from the position it maintains during the summer abreast Greenland. Yet it is probable that the deeper portion of the Gulf currents maintain their ground in under currents, and are only thinly covered by the drifting surface waters of the arctic, which sweep down from the north, and assist the westerly winds so much in forcing the Gulf Stream off shore. Thus we insist that tropical waters are moved from their high sea-levels into high latitudes mainly by attraction caused through the westerly winds creating low sea-levels along the extended shores of continents.

Not only does Dr. Croll fail to explain the true cause of tropical waters reaching high latitudes; he also fails to explain why Greenland and Iceland, and other countries situated in high northern latitudes, are growing colder. On the contrary, according to his theory they should be growing warmer. But we learn from their history that for the last eight hundred years their climate has been gradually lowering in temperature, although the northern winter solstice is in perihelion.

It will be seen that our explanation of the great climatic changes, in the high latitudes of the globe, also accounts for the warm climate of the carboniferous period. The warmth required for that age could scarcely have been supplied by an ocean as limited and insulated as the Atlantic of the present time. But when we consider that the tropical oceans during the carboniferous period evidently did maintain a higher sea level than now, and consequently the warm equatorial currents must have found a passage through the ancient African seas into the North Atlantic, we can well account for the continuous warm climate which existed dur-

ing the forming of the coal beds on the eastern slopes of North America, and on the shores of Great Britain. During this age it is probable that both hemispheres were mostly free from ice; which accounts for the ancient tropical seas being supplied with water. Thus it would follow that the Cape Horn channel would be so greatly reduced as to partly destroy the independent circulation of the southern ocean; consequently, so long as such conditions lasted, the ice would not form in immense ice-caps around the poles. And it seems that the first ice periods must have happened in the antartic regions, where the independent circulation of the polar seas were the least obstructed. But it is probable that all of the early southern ice-caps were not of sufficient weight to drain the Sahara seas, but were able to lay bare at different periods the carboniferous lands of North America and Great Britain. The ice-sheets of early ages must have scoured the Cape Horn channel and caused it to become much enlarged; consequently, giving a more independent circulation to the southern seas. Therefore the southern ice-caps of later periods were probably more extensive than those of earlier ages, because the widened channel required a larger ice-cap to close it. In this manner the southern ice-caps at length obtained weight adequate to completely drain the Sahara seas, and so prevented the direct flow of warm water from the Indian Ocean into the Gulf Stream; thus the heat of the tropical Atlantic currents was reduced sufficiently to render them unable to prevent the arctic seas from chilling, especially while the arctic channels remained open. Nevertheless, under favorable conditions the great forces of nature may have caused ice-caps to form in the high latitudes of the north in earlier ages. For it is reported that conglomerate occurs with boulders deposited previous to the carboniferous era, which appears to show the action of ice, and that an ice-burdened southern hemisphere was able to drain the Sahara Seas, and deprive the North Atlantic for a period of its greatest source of heat prior to the carboniferous age.

While considering the changes effected by the winds and

waters, it is well to bear in mind that the site of extensive low lands of the present age, at an early geological period were covered by the sea, with the ocean waters at their present level. For we know that the beds of the ancient seas of Northern Africa have been raised by vast calcareous deposits, and extensive basins filled by the deltas of large rivers; and it appears also that the earth's crust has absorbed a considerable portion of the ancient seas. At all events, the great geological changes which have been wrought will considerably influence the working of nature in future ages, because of the more obstructive barriers raised between the tropical oceans.

But while we consider how the low portions of continents have been submerged, it is evident that while other lands have had their barriers broken, the great American continent has stood through many ages an obstruction to the independent circulation of the tropical seas; with its mountain ranges reaching across the zones it has, with the aid of great prevailing winds, combined with the causes we have explained, turned the tropical currents at different eras far into the high latitudes, and thus brought about the several periods of mild and frigid weather.

Thus from the past operations of nature we contemplate the climatic agents which now govern the temperature of the high latitudes of the globe; and we find that the ice is gradually increasing around the poles on both hemispheres, because of the independent circulation of the waters of the high latitudes. Especially is this the cause of the growing ice-sheet of the southern hemisphere. We have also shown how the northern regions are chilled because the arctic currents are constantly forcing southward the waters of the Gulf Stream.* Furthermore we have shown how this

* It is probable that the uncommon low temperature of our present winter is owing to the arctic channels leading into Davis Strait being unusually free from ice; the ice which has moved out of the northern straits the last two summers being greater in quantity than generally reported, therefore causing a more independent circulation of the arctic waters; consequently less tropical water penetrates the northern seas to subdue the coldness of winter in the northern regions, than during years when the arctic channels are more obstructed.

great carrier of heat has been greatly reduced since the ending of the great northern ice-age through the disappearance of the great Sahara Sea, and the consequent separation of the North Atlantic from the direct flow of the great equatorial waters of the Pacific and Indian oceans. Yet, we should consider that the equatorial heat of these oceans has been able to reach the Atlantic in a diminishing stream through a branch of the Mozambique current, called at the Cape of Good Hope the Lagullas current, which at times runs a large stream of warm water into the Atlantic; being attracted by the low sea-level abreast the west coast of Southern Africa, from whence it is blown by the south-east trade-winds toward the Gulf of Mexico, and so becomes a feeder for the Gulf Stream. But even this single source of heat from the great tropical oceans of the world is being gradually subdued through the constant growth of the great southern ice-cap. Because while the southern ice-cap increases, the strong westerly winds encroach proportionally on the lower latitudes, and thus prevent the waters of the Lagullas current from passing around Africa into the Atlantic, and because of this increase of cold in the southern ocean the warm easterly winds which blow over the lands of the Cape Colony during the summer probably extend a less distance southward over the sea than formerly.

Yet the Atlantic derives considerable heat from the great tropical rivers which empty into it. The Congo, Niger, Amazon, Orinoco, and many other large streams add their warmth to its surface waters, which contribute to the Gulf Stream. The largest rivers of North America, Europe, and northern Asia, also add their summer heat to the northern seas. Consequently the increase of ice on the lands of the north is slow, and will thus continue so long as the summer sun is able to melt away the snow which gathers in winter and heat the ground sufficiently to attract the winds from temperate regions. But when the winter snow once gains possession of such lands, the sun's rays will be largely reflected into space without imparting much warmth to the earth.

Thus it appears that the climatic agents now operating on the northern latitudes furnish all the conditions requisite for the slow yet constant increase of cold, and consequently the accomplishment of a future ice-period.

This gradual increase of cold in the high latitudes renders the oceans of the temperate zone more boisterous in both hemispheres than in the days of the early navigators. Many old seamen are of the opinion that such seas have increased in ruggedness during their own experience.

We have before mentioned the present frigid condition of Greenland. This country, when first discovered, received its name from the Northmen because of its abundant verdure; but the lands once so fertile are now occupied by enormous glaciers.

The old accounts of the prosperity of Iceland seem strange to those who now visit its inclement shores.

The present unhappy condition of the agricultural people of Ireland may be owing somewhat to the growing inclemency of its climate.

The agricultural failures of Great Britain have been much relieved during the last generation through the great increase of manufactures.

We know that recent winters have been unusually cold in Europe, and that the seas have proved to be remarkably stormy.

Arago did not refuse to believe that the laws regulating the temperature of western Europe had notably altered; this is proved, he says, by the gradual retrogradation of the vineyards toward the south.

In fact there appears no lack of historical proof to show that the climate of many northern countries is slowly becoming colder.